Methodology to Estimate Pollutant Load Reductions Final Report Executive Summary

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US Army Corps of Engineers and the Lahontan Regional Water Quality Control Board

Introduction and Background

Lake Tahoe is designated an Outstanding National Resource Water (ONRW) due to its extraordinary clarity. However, since 1968, scientists have measured a decline in water quality. The lake is now considered water quality impaired due to clarity loss resulting from fine particulates (<20 um), nitrogen, and phosphorous. The lake is currently listed as impaired under Section 303(d) of the Clean Water Act in both California and Nevada. The California Lahontan Regional Water Quality Control Board (Lahontan), and the Nevada Division of Environmental Protection are currently collaborating on the development of a Lake Tahoe Sediment and Nutrients Total Maximum Daily Load (TMDL).

A key objective of the TMDL program is the development of accepted and consistent methodologies for estimating pollutant load generation and reduction associated with major pollutant source categories (Upland, Stream Channel Erosion, Atmospheric Deposition, and Groundwater). The scope of work for this project is to develop, test, and compile methodologies that can be used to estimate or quantify pollutant load reductions for storm water quality improvement projects and best management practices (BMPs) in the Lake Tahoe Basin. In particular, the focus of this project is on pollutant load reductions associated with storm water runoff from developed areas. This work will directly support Phase II of the TMDL program, which will involve alternatives and allocations for load reductions. The load reduction methodology is also expected to support Phase III, which involves project implementation, monitoring, and adaptive management to meet the load reduction targets.

A methodology is ultimately needed that:

- Addresses different geographic scales (e.g., regional, project, individual BMP),
- Addresses the effects of both source controls and storm water treatment facilities,
- Addresses maintenance and monitoring effects,
- Focuses on pollutants of concern for Lake Tahoe (inorganic particulates <20 microns, nitrogen species, phosphorous species,
- Applies to different stages of project development (e.g., conceptual planning, watershed analysis, detailed design), and
- Can be adapted to support the future TMDL implementation system.

A Project Advisory Committee (PAC) consisting of representatives from the U.S. Army Corps of Engineers (Corps), Lahontan, and UC Davis was established to guide the technical development and to assist in decisions regarding the scope of the project and future development. The compiled methodology should be viewed as a "first step" towards the ultimate goal of pollutant load prediction in the Lake Tahoe Basin. It is the goal of the TMDL program to develop similar methodologies to address all significant pollutant sources (e.g., upland erosion, stream erosion, atmospheric deposition) and to track pollutant reductions occurring in all source categories. The project described here is one component in the development of these technical tools, which will be full implemented after approval of final TMDL in spring of 2009.

Project Scope and Purpose

The project is defined in three major tasks:

Task 1 - Investigate Local and Regional Water Quality Improvement Practices
This task involved conducting interviews with local agencies to discuss current practices and needs in BMP selection and design criteria; performance and regulatory standards to be met; analytical tools and data sources used; criteria for evaluating impacts and benefits; and maintenance and monitoring practices.

Task 2 - Summarize Existing Information and Programs at a National Level
This task involved two components: literature review and conducting interviews with nationally recognized researchers and practitioners in the field of storm water management.

Task 3 - Develop Load Reduction Methodology
This task involved initial screening of methods, development and testing of methods, compilation of the methodology, preparation of examples, and review with Lake Tahoe Basin stakeholders.

Lake Tahoe Water Quality Practice

Results of the local survey conducted in Task 1 indicated that current practices in the Lake Tahoe Basin are neither state-of-the-art with regard to water quality analysis nor very efficient with regard to implementation of water quality projects. This situation is at least partly the result of a lack of standard practices and design criteria, including a lack of connection between numeric effluent standards and design. Implementing agencies have no consistent set of design criteria for water quality projects, and design staff and consultants must navigate the review and regulatory process by demonstrating that the design is the best practicable given constraints. This standard is nearly always subject to qualitative interpretation, resulting in lengthy project delivery times and uncertain results in water quality performance. Key recommendations that came out of this process called for:

- Standardized design criteria based on water quality performance,
- Hydrologic design manual that addressed drainage and water quality design criteria,
- Load reduction methodology based on best available science, and
- Monitoring strategy to improve the methodology over time.

National Water Quality Practice

National water quality practices were investigated through a literature review, a telephone survey with nationally recognized storm water researchers, and a telephone survey of agencies outside the Tahoe Basin that are addressing storm water as part of a TMDL.

The literature review indicated that a load reduction methodology, to be effective, needed to address both the hydrology and water quality components of load generation and reduction. This required a methodology that addressed precipitation-runoff and pollutant mobilization, source controls, storm water runoff pollutant concentrations, and distributed and centralized storm water treatment facilities. Source controls are defined in this report using two categories: pollutant source controls, and hydrologic source controls. Pollutant source controls limit the supply of pollutants on the watershed and therefore limit the potential for certain pollutants to be mobilized and transported during a storm event. Hydrologic source controls limit runoff by retaining or providing for the natural processes of interception, infiltration, and evapotranspiration.

A national survey was conducted that involved telephone interviews with nationally recognized experts in storm water management. These interviews were intended to provide unbiased insight into the advantages and disadvantages of various methodologies identified in the literature review. Although each expert had specific points of views, the following are general conclusions from the interviews:

- Pollutant loads, to be meaningful, should represent a range of climatic conditions that called for a methodology accounting for all, or some portion of the historical record of precipitation, rather than a discrete event perspective;
- Hydrologic analysis should be conducted to address most processes, whereas the current state of practices for water quality was, by necessity, more empirical;
- Adaptive management is key in terms of improving the reliability of input data, verifying modeling assumptions, and providing data for calibration and verification;
- Hydromodification effects should be addressed;
- Design standards at this time should rely on hydrologic (e.g., percent of runoff volume treated), rather than water quality treatment performance (e.g., percent reduction in concentration) criteria.

A national survey of key agencies that are active in storm water management as part of implementing TMDLs was also conducted via telephone. The interviews addressed implementation and process, as well as technical approach. Key finding were:

- A range of load generation methodologies are used, from simplified methods (e.g. export coefficients in lbs/acre) to sophisticated continuous watershed models (e.g. Hydrologic Simulation Program FORTRAN-HSPF);
- Calculations of pollutant load reductions was very limited;
- About half the agencies had some involvement in pollutant trading or offsets;
- Most agencies supported and utilized adaptive management.

Development of Approach

Based on the findings from the interviews and literature review, it became apparent that the chosen methodology needed to address the following:

1. The methodology should be as quantitative, objective, and as consistent as possible to reduce subjectivity in project review and permitting.

2. Although a consistent or standardized methodology is needed, flexibility for the user is also required to account for project-specific conditions.
3. A better connection is needed between pollutant load reduction performance and design. The methodology should estimate load generation and reduction for all pollutants of concern.
4. Pollutant source controls and hydrologic source controls will continue to play a significant role in water quality improvement, and their effects need to be integrated into the method.
5. Better tools for estimating the effects of hydrologic source controls are available, but are currently beyond the scope of most projects. A simple method is needed to integrate these techniques into project assessment and design.
6. Maintenance of BMPs is a significant factor in selection and performance, and needs to be incorporated into the methodology.
7. The methodology should account, to the extent feasible, for variations in design (sizing, configuration, setting, etc.) of BMPs that occurs as the result of site constraints and other constraints.

Based on these guidelines, the methodology was conceived in 3 elements: (1) hydrology, including the effects of hydrologic source controls in reducing runoff; (2) pollutant load generation, including the effects of pollutant source controls; and (3) storm water treatment, focusing on centralized BMPs that remove pollutant loads from collected runoff. Using this approach, the overall pollutant load reduction associated with water quality improvements is the net result of hydrologic source controls, pollutant source controls, and centralized storm water treatment.

Screening of Approaches

The approach for each element was then evaluated based on information gained from the literature review and interviews, the experience of the consultant team, and a series of discussions and meetings with the PAC. Factors considered included level of complexity; input data requirements given current and anticipated data sources of information; ability to address project scale applications; and interface with the larger LSPC watershed model being developed for the Tahoe Basin TMDL program.

In order to address TMDL needs to track pollutant load reductions and provide credits towards allocations, a methodology is needed to estimate potential load reductions at a finer resolution (smaller scale) than the LSPC watershed model. The scope of work for this project noted that a methodology is ultimately needed for application at the individual BMP, project, and regional scales. The screening of potential methods focused most heavily on the project scale, based on perceived needs from the Lake Tahoe interviews in Task 1. The approach selected was to develop a methodology that is applicable to the project scale with catchments on the order of 5 to 100 acres in size, as this is the scale at which most storm water quality improvements in the Tahoe Basin are designed. Development of modifications to the methodology to address a larger range of scales was deferred with the concurrence of the PAC so that project resources could be focused on the scale believed most applicable to projects. Further development of the methodology (and perhaps of the watershed model) will need to address this topic. However, various options may be explored for application of each tool in the TMDL program, and direct linkage may not be necessary.

Hydrology - With respect to the hydrologic element, the continuous process-based methods involve fairly complex hydrologic modeling with numerous input data and calibration requirements. The application of these methods is not common in the Tahoe Basin, and the level of complexity may conflict with the objective of the making the methodology practical for Lake Tahoe Basin implementers. For this reason, the screening process involved consideration of a simplified application of continuous hydrologic simulation through a user-interface. The selected approach was therefore to utilize a more process-based approach to estimating runoff, while minimizing the need for detailed knowledge regarding the specific continuous modeling tool chosen.

Pollutant Load Generation - With respect to the load generation element, the project team felt that at the desired project scale, a process-based approach would likely lead to a very high level of complexity to model load generation from various sources. The selected approach was therefore to utilize empirical estimates of concentrations characteristic of particular land uses. In addition to spatially distributed pollutant sources that can be characterized by land use, there is a need to estimate loads from specific sources that are not represented by Tahoe Basin water quality data for particular land uses. These loads might be quite large if associated with significant problems. For example, an eroding gully contributes disproportionately high loads per unit area. For this purpose, the approach selected was to combine empirical estimates based on land use with estimates of loads for specific sources.

In addition to estimating pollutant loads generated from an existing condition, a method is needed in the load generation element to estimate the pollutant load generated after implementation of pollutant source controls. Sufficient data on effectiveness of pollutant source controls was not found to be readily available for use in directly estimating loads or load reductions associated with pollutant source control implementation. However, the PAC agreed that inclusion of pollutant source control BMPs is an important factor in the overall performance of a storm water management system, and should be incorporated into the methodology.

Storm Water Treatment - With respect to the storm water treatment element, similar constraints regarding process-based modeling applied. Pollutants of concern for the Lake Tahoe TMDL are fine sediment and biologically available nutrients. Very little monitoring data is available on particle size distributions in runoff, fractionation of nutrient loads, effectiveness of BMPs on the fine sediment and dissolved nutrient fractions, and the variability in effectiveness under different hydraulic conditions (e.g. residence time). Although physically-based estimates are ultimately desirable, only one treatment process was identified that the project team had confidence could be well represented by physically based computations. Particle settling theory provides a means for estimating fine sediment removal in some storm water treatment BMPs based on time variant hydraulic conditions.

For constituents other than fine sediment, the project team felt that physical and chemical processes in BMPs are not well enough understood at present to warrant development of a physically-based approach. The selected approach for development of the methodology therefore combines physically-based fine sediment removal estimates and empirical/statistical estimates for typical effluent concentrations of other pollutants of concern. Achievable effluent quality was selected as a preferred approach over an estimated percent removal.

Summary of Screening Results

The following list summarizes decisions on methods and approach agreed upon by the PAC during the screening process.

- The pollutant load reduction methodology will focus on pollutants of concern for Lake Tahoe in surface water generated in urbanized areas and subject to potential removal by storm water treatment BMPs.
- Pollutants of concern will be quantified, and are defined as total and fine sediment (less than 20 microns), total and dissolved nitrogen, and total and dissolved phosphorus.
- The overall approach is organized into three main elements: 1) Hydrology, 2) Pollutant Load Generation, and 3) Storm Water Treatment.
- The hydrology element will estimate runoff using continuous hydrologic simulation.
- Due to the complexity of continuous hydrologic simulation, a tool will be developed to lessen the complexity and data requirements of the hydrologic estimation, making the methodology more practical for application by implementers.
- Continuous hydrologic simulation will account for reduction in runoff volumes from implementation of hydrologic source controls.
- Pollutant load generation will be based primarily on characteristic event mean concentrations (EMCs) for various land use categories, but will include alternative methods, referred to as specific sources, for pollutants generated that can be considered independent of a land use category or land use condition.
- Pollutant source control implementation will be accounted for in the pollutant load generation element.
- Pollutant source controls include maintenance practices, drainage improvements, stabilization activities, and road sanding management.
- Storm water treatment computations will primarily use empirically-derived performance data combined with some physically-based simulation for fine sediment removal. Empirical performance data will use median achievable BMP effluent quality rather than percent removals.
- Storm water treatment BMPs represented in the methodology will be selected based on common facilities and designs currently implemented in the Tahoe Basin.

Description of Methodology

Figure 1 conceptually illustrates the three major elements to the methodology: 1) hydrology, 2) pollutant load generation, and 3) storm water treatment. User input is required for each element, and the results of each are used in subsequent elements. Pollutant load generation is estimated based on an analysis of hydrologic characteristics, watershed characteristics, and land uses that affect pollutant sources and delivery. Storm water treatment represents major treatment BMPs (e.g., wet and dry basins, wetland treatments, bioswales, infiltration galleries, and filtration systems) and is based on design parameters, inflowing loads, and hydrologic characteristics. The computed pollutant load represents a combination of hydrologic source controls, pollutant source controls, and storm water treatment.

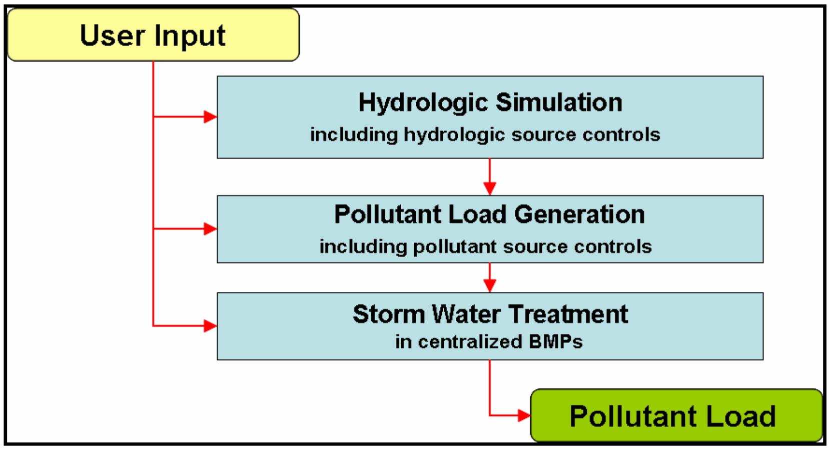

Figure 1 - Conceptual Methodology Diagram

The following describes the methodology for each of the three computational elements.

Hydrology - Computation of hydrologic characteristics for pollutant load generation and storm water treatment are based on long-term simulations to represent the effects of natural hydrologic variability on pollutant loads. This approach is preferred because it takes into account the sequence of storms, wet vs. dry years, and the effects of infiltration and evapotranspiration on the water balance. This approach requires use of a long-term meteorological data set. The synthetic MM5 data set was selected as the meteorological input, developed by UC Davis. The methodology requires user input for the most sensitive hydrologic parameters including the MM5 grid cell that the project is located within, impervious/pervious area, impervious connectivity, soils information, vegetation information, and the infiltration characteristics. The MM5 data set presents the opportunity to conduct long-term (40 years) simulations on an hourly time step using geographically specific meteorological inputs. The initial version of this data set has shown promise, and will be further developed by calibration to observed data so that it can eventually be used as the basis of the watershed LSPC model for the TMDL.

The hydrologic methods in the methodology are applicable to pre- and post-project conditions. In addition to simulating the runoff characteristics of a project area, the methodology allows for input of design criteria for sizing treatment BMPs and for specifying the rates at which storm water treatment BMPs will drain. The average annual runoff volume from the continuous simulation is used by the pollutant load generation element to determine average annual pollutant loads generated.

Pollutant Load Generation - The methodology employs two techniques to estimate pollutant load generation: 1) spatially distributed source accounting (land use based pollutant loading), and 2) specific source accounting (e.g., gully erosion, eroding disturbed areas, road sand). Spatially distributed source accounting estimates pollutant load generation using the land use-based event mean concentrations (EMCs) from Tahoe Basin monitoring data and the average annual runoff volume, which is computed from the hydrology element. These EMC values and land use categories were developed as part of the TMDL program in support of the Watershed LSPC Model. A detailed description of how the land use categories and EMCs were developed for the TMDL program will be included in the Draft Technical TMDL document to be released in the summer of 2006. EMCs include land use-based estimates of total suspended sediment (TSS), fine sediment (<20 um) as a percentage to TSS, total and dissolved nitrogen, and total and dissolved phosphorus.

Specific source accounting estimates pollutant load generation for sources that are generally not associated with land uses, (e.g., road sand, gullies, drainage system degradation, etc). Specific source accounting estimates pollutant load generation by summing the relative yield of pollutants from the defined specific source on an average annual basis (e.g., average annual road sanding on a specified application area, average annual gully sediment yield based on gully advancement, etc.).
Specific source accounting requires user input data that is unique to the specific source. The two techniques (spatially distributed sources and specific sources) are used in combination to provide a means to estimate total pollutant load generation for project area conditions

Storm Water Treatment - The reduction in pollutant load achieved by a storm water treatment BMP depends on the portion of the runoff treated and the extent of treatment achieved. The methodology uses a combination of empirically-derived and physically-based methods to represent the range of BMP performance.

Standard design parameters are required for a selected list of storm water treatment BMPs (e.g., wet and dry basins, wetland treatments, bioswales, infiltration galleries, and filtration systems). Examples of standard design parameters include hydraulic capacity and infiltration rates. These parameters are used to estimate the runoff capture ratio and bypass ratio. Performance of volume-based BMPs for fine sediment uses a unit process approach (settling theory based on hydraulic conditions), while performance for nutrients is estimated using empirical data for achievable effluent quality. Performance of flow-based BMPs for all pollutant of concern is estimated using empirical data for achievable effluent quality. Characteristic effluent concentrations are used, recognizing that BMP performance is often better represented by an achievable effluent quality rather than a fixed percent removal, which causes estimates for load removal to vary linearly with influent quality (Strecker et al. 2001).

The methodology also takes into account multiple storm water treatment BMPs and flow routing through and around the storm water treatment BMP(s). Both the treated load and bypassed load may be routed to either the outfall or a downstream BMP. Up to three storm water treatment BMPs may be simulated in sequence at the end of a drainage catchment, either in parallel or in series.

Pollutant Load Reduction - The three major elements of the methodology – hydrology, pollutant load generation, and storm water treatment – are described separately in this executive summary but the elements are inherently interdependent for calculation of pollutant load reduction. Modifications to input assumptions and data for any of the three elements may increase or decrease pollutant loading depending on the relative change in hydrology or water quality. All three elements may be used to estimate pollutant load reduction, with each element designed to represent certain water quality functions and BMPs.

PLRE-STS

In order to organize and evaluate the applicability of the selected approach, the PAC agreed that the conceptual methodology developed in this report would be best illustrated and evaluated using a spreadsheet tool: referred to as the Pollutant Load Reduction Estimator – Spreadsheet for Tahoe Storm Water (PLRE-STS). However, development of a computational tool was not included in the original scope of work. The main work product for this report is the conceptual methodology, and the PLRE-STS should be considered a prototype computational tool used to illustrate and evaluate the conceptual methodology. In the context of this report, "prototype" means that a relatively complete computational tool is ready for initial testing and further development. The completed products of work, defended as a significant advancement in the development of a pollutant load reduction methodology for storm water quality improvement projects in the Lake Tahoe Basin, are the selected approach and conceptual methodology described in this report.

The PLRE-STS is a single Excel file containing multiple worksheets used for data input, internal data lookup, and output summaries linked internally and externally by Excel macros and computer code. The PLRE-STS accepts user defined inputs for project area characteristics and design criteria and provides output on hydrologic characteristics, pollutant loads, and pollutant load reductions. The overall design of the PLRE-STS is intended to be practical for application by implementers. While a user of the PLRE-STS does not need to be an expert in hydrologic and water quality calculations they should have some training in hydrology, water quality, and the application of models. The PLRE-STS allows a continuous hydrologic simulation to run "in the background" based on simplified input parameters, and automatically links this simulation to load generation and load reduction computations. For incorporation into the PLRE-STS, the U.S. EPA Storm Water Management Model (SWMM) was selected as the hydrologic engine for continuous simulation. The PLRE-STS provides a simplified and flexible interface to SWMM.

In addition to the automated techniques, the structure of the PLRE-STS was designed for transparency and flexibility. For example, default values are provided in look-up tables for many of the pertinent input parameters for hydrologic and water quality analysis in the Lake Tahoe Basin (e.g. soils data, BMP effluent concentrations, characteristic land use concentrations, etc.). The lookup tables have been designed to allow a user to deviate from the default values if project specific data or professional judgment warrants. This built-in flexibility allows for simple refinements to the methodology in the event that new monitoring data or policy decisions result in a revision to the current data assumptions in the PLRE-STS.

The PLRE-STS computes pollutant loads for user defined conditions – the load reduction attributed to changes between pre-project and post-project conditions must be determined by comparing output for the two conditions. The PLRE-STS estimates pollutant loads at the drainage catchment outlet for total sediment, fine sediment (less than 20 microns), total nitrogen, dissolved nitrogen, total phosphorus, and dissolved phosphorus.

Limitations of the Methodology

The current methodology, like many such methodologies that are attempting to address complex hydrologic and water quality processes, has a number of assumptions and limitations.

Hydrologic Limitations

- Simulations limited to one catchment only, and for either pre-developed or post-developed conditions;
- No hydraulic routing in runoff computations;
- Lumped parameters represent the entire catchment;
- Constant loss rates are used in BMPs;
- Bypassed volume is computed from water quality design parameters, methodology does not consider specific hydraulic characteristics of diversion structures;
- Total runoff volume distributed among land uses based on imperviousness;
- Results dependent on MM5 data, which currently require additional calibration.

Water Quality Limitations

- Spatially distributed pollutant source control effectiveness is based on "tiers", but insufficient data is presently available to directly relate tiers to water quality improvement;
- Specific source loading estimates are not physically based and have considerable uncertainty;
- Pollutant load generation techniques do not automatically protect against potential double counting;
- Delivery ratios are user-defined and require subjective judgment;
- BMP effluent quality in storm water treatment is based on national database rather than Tahoe-specific data; and
- High amount of variability in land use EMC data used.

Recommended Next Steps

The methodology and the associated PLRE-STS should be viewed as a first step in the ongoing development of quantitative analytical tools for estimating Tahoe Basin pollutant loads. The conceptual methodology is a major advance in the approach to calculating pollutant load reductions in the Tahoe Basin, but it should be recognized that the computational tools have only been developed to the prototype level at present. Much additional work is necessary to refine this methodology, both to advance the methods that are used and to improve the methodology and the PLRE-STS so that they can be used broadly by project proponents and accepted by regulatory agencies.

The following section outlines recommended development tasks that should occur prior to release of a beta version of the PLRE-STS. Beta version, as used here, means a computational tool that has undergone sufficient testing and development to be released for independent application and testing by intended users at the project scale.

1) Incorporate revised MM5 data;
2) Test and verify parameters in the PLRE-STS using Tahoe Basin monitoring data;
3) Conduct test applications at the project scale;
4) Provide clearer reporting and review tools;
5) Consider refinements to spatially distributed source control techniques;
6) Consider refinements to specific source accounting;
7) Consider refinements for estimating pollutant load reductions in BMPs;
8) Refine methods for accounting for private property BMP implementation;
9) Develop an abbreviated users manual;
10) Provide clearer reporting and review tools;
11) Provide more automated error checking within the spreadsheet tool;
12) Improve hydraulic routing in BMPs;
13) Develop a tool for creating rainfall and temperature interface files;
14) Develop methods for application of flow-duration information; and
15) Improve representation of maintenance effects.